PB81-211690

Effect of Elevated Water Temperature on Insect Emergence in Outdoor Experimental Channels

(U.S.) Environmental Research Lab.-Duluth
Monticello, MN

1981

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/J-81-210	2. Journal Article
3. PB81 211690	
4. TITLE AND SUBTITLE: Effect of Elevated Water Temperature on Insect Emergence in Outdoor Experimental Channels	5. REPORT DATE: June 1931
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): Kathleen J. Nordlie and John W. Arthur	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Monticello Ecological Research, Environmental Research Laboratory-Duluth, P.O. Box 500, Monticello, Minnesota 55362	10. PROGRAM ELEMENT NO. 1BA 608
	11. CONTRACT/GRANT NO. None (in-house)
12. SPONSORING AGENCY NAME AND ADDRESS: Environmental Research Laboratory-Duluth, MN, Office of Research and Development, U.S. Environmental Protection Agency, Duluth, Minnesota 55804	13. TYPE OF REPORT AND PERIOD COVERED: Final Report 4/1977-9/1977
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

PUBLISHED: Environ. Pollut. (Series A) 25: 53-65 (1981)

16. ABSTRACT

Emergence of adult aquatic insects was evaluated weekly with plexiglass traps positioned in two outdoor experimental channels from April through August 1977. One channel was seasonal Mississippi River water temperature and the other maintained at 10°C above. Maximum water temperatures reached 31.0°C in the ambient and 40.8°C in the heated channel. Chironomids comprised 84% of the insects collected in both channels. Percentage composition differed between the ambient and heated channels for the chironomid taxa while the mayfly, damselfly and caddisfly taxa were more similiar. The temperature in the heated channel (10°C above ambient) advanced the emergence of two Chironominae, one Orthocladiinae, one Ceratopogonidae and one Zygopteran species by one to four weeks. Few insects emerged from the heated channel during the period of maximum temperature. Insect emergence was spatially distributed throughout each channel even though dissolved oxygen concentrations were near zero at sunrise and supersaturated at mid-afternoon hours at downstream stations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Aquatic Biology Entomology Field Tests Insects Thermal Environments Thermal Gradients	Aquatic Insects Emergence Outdoor Channels Temperature Effect	6C 6S 13B

18. DISTRIBUTION STATEMENT: RELEASE TO PUBLIC	19. SECURITY CLASS (This Report): UNCLASSIFIED	21. NO. OF PAGES: 13
	20. SECURITY CLASS (This page): UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

PB81-211690

EPA-600/J-81-210
Journal Article

a reprint from

Environmental Pollution

an International Journal

Edited by

KENNETH MELLANBY

Published by

APPLIED SCIENCE PUBLISHERS LTD

Ripple Road, Barking, Essex, England

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

Environmental Pollution (Series A) **25** (1981) 53–65

EFFECT OF ELEVATED WATER TEMPERATURE ON INSECT EMERGENCE IN OUTDOOR EXPERIMENTAL CHANNELS

KATHLEEN J. NORDLIE & JOHN W. ARTHUR

Monticello Ecological Research Station, US Environmental Protection Agency, Monticello, Minnesota 55362, USA

ABSTRACT

Emergence of adult aquatic insects was determined weekly with plexiglass traps positioned in two outdoor experimental channels from April through August 1977. One channel was seasonal Mississippi River water temperature and the other maintained at 10°C higher. Maximum water temperatures reached 31·0°C in the ambient and 40·8°C in the heated channel. Chironomids comprised 84% of the insects collected in both channels. Percentage composition differed between the ambient and heated channels for the chironomid taxa while the mayfly, damselfly and caddisfly taxa were more similar. The temperature in the heated channel (10°C above ambient) advanced the emergence of two Chironominae, one Orthocladiinae, one Ceratopogonidae and one Zygopteran species by one to four weeks. Few insects emerged from the heated channel during the period of maximum temperature. Insect emergence was spatially distributed throughout each channel even though dissolved oxygen concentrations were near zero at sunrise and supersaturated at mid-afternoon hours at downstream stations.

INTRODUCTION

Emergence of aquatic insects is a critical stage in the life cycle and is useful for determining the impact of pollutants on aquatic systems. Factors that influence emergence include water temperature, photoperiod and dissolved oxygen (Nebeker, 1971, 1972; Danks, 1978). Alterations of normal water temperatures can cause different developmental rates in the life cycle and thus produce variations in emergence time (Brittain, 1976; Newell & Minshall, 1978).

Many studies have been conducted on the effects of elevated water temperatures on benthic macro-invertebrates, but relatively few authors have investigated the effect on emergence in the field. Coutant (1967) and Wrenn *et al.* (1979) found

Environ. Pollut. Ser. A. 0143-1471/81/0025-0053/$02·50 © Applied Science Publishers Ltd, England, 1981
Printed in Great Britain

increased temperature advanced emergence times of some insect species while Langford & Daffern (1975) could not detect any effects from increased temperature.

This study represents a portion of a comprehensive study to evaluate effects of thermal additions to macro-invertebrates and fish populations in two outdoor experimental channels, one maintained at seasonal Mississippi River water temperature, the other at 10 °C above. The intent and general objectives of the outdoor channel temperature studies were earlier described by Mount (1969). Adult insect emergence in the two channels was compared to determine if the increased water temperature would produce an alteration of population structure and emergence patterns.

METHODS AND MATERIALS

Experimental facility

This study was conducted at the Monticello Ecological Research Station, Monticello, Minnesota, a field station of the USEPA Environmental Research Laboratory—Duluth, Minnesota. The research facility is located adjacent to the Monticello Nuclear Electric Generating Plant (Fig. 1). The water source for eight outdoor, man-made, experimental channels at the research facility is the Mississippi

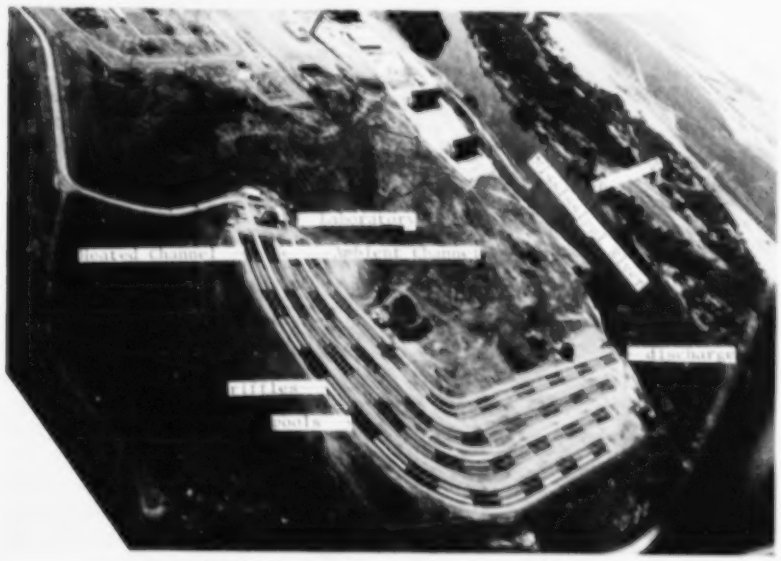

Fig. 1. Aerial view of the Monticello Ecological Research Station.

River. The research area for this study consisted of two channels 520 m in length, each composed of nine alternate pools and eight riffles. The mud bottom pools were 30·5 m long, 3·6 m wide and 76–86 cm deep. Riffles were constructed from 2 to 5 cm diameter gravel and measured 30·5 m long, 2·4 m wide and 10–20 cm deep. Mean surface area for each channel was 0·14 ha and water volumes about 568 m^3. One channel was maintained at Mississippi River temperature and the other at 10 °C above. For the heated channel, river water was passed through a heat exchanger using power plant discharge water as the heat source. Mean flow to each channel was maintained at 2·3 $m^3 min^{-1}$ with a range of 2·1–2·4 $m^3 min^{-1}$.

Sampling procedures

Plexiglass emergence traps were positioned at five locations in each channel: upper riffle and pool, middle pool, lower riffle and pool. Samples were collected weekly from 15 April 1977 to 1 September 1977. Each trap (Fig. 2) was constructed of a plexiglass skylight supported by 2 mm thick plexiglass sides, measuring 43 cm × 30 cm. The top half of two sides was composed of 0·2 mm mesh nylon screening to permit easy washing of the trap. A removable plexiglass baffle measuring 32·5 cm × 43 cm was placed inside the trap at a 45° angle, 10 cm from the bottom of the trap to prevent loss of insects in the water. A screw top jar with a nylon bottom (0·2 mm openings) was glued over a hole in the top of the skylight to serve as a container for

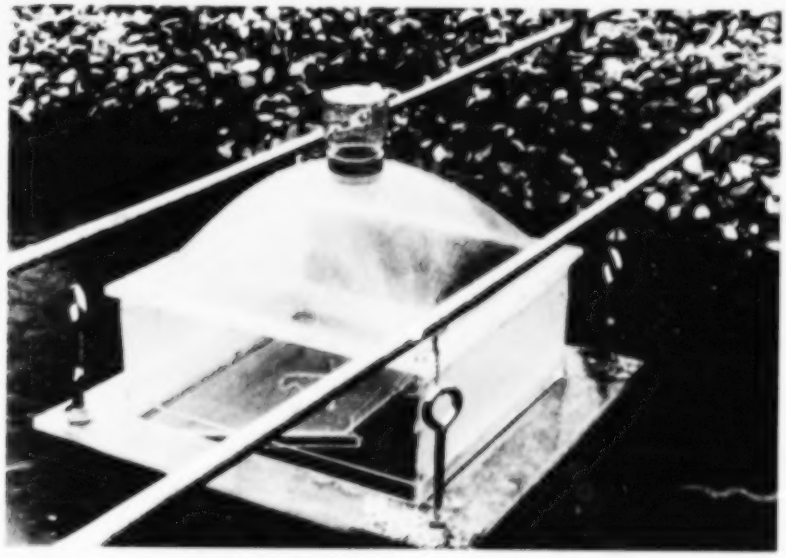

Fig. 2. Emergence trap in place in a riffle.

collection of insects when the trap was emptied. On the outside of a trap, plexiglass strips 2·5 cm wide and 12·7 cm from the bottom allowed the trap to rest in a plexiglass base which suspended the bottom of the trap approximately 9 cm below the surface of the water. The base, held by 25 cm eye bolts in each corner, was wired to iron poles that extended across a channel. The wires allowed easy adjustment of the trap to varying water levels. A sliding plexiglass bottom inserted through a slot on one side of the trap prevented sample loss upon removal. The traps were collected once a week, inverted on a stand, and the insects washed into the top jar with a fine spray of well water. Insects were preserved in 70% ethyl alcohol.

Samples were identified using a stereo microscope (magnification of 0·7 to 3×) and a compound microscope (magnification 2·5 to 40×). Chironomids were subsampled with a Folsom plankton splitter when more than 300 individuals were present. Repeated trials ($N = 12$) indicated the subsampler was within 20% accuracy in estimating the abundance of insects from the original sample.

Peak emergence periods were determined for each major group of insects. Individuals were identified to genus and species where possible. Emergence peaks were defined as those samples having at least 20 individuals of the same type in a trap and composing greater than 50% of the sample. For each group, a two-way analysis of variance was used to determine abundance differences by channel and location.

Physical and chemical characteristics of the channel waters were measured throughout the study. Water temperatures were taken at six locations in each channel with Type 'T' thermocouples, and recorded at 3-h intervals on Leeds and Northrup Speedomax W recorders. Substrate temperatures were recorded by thermocouples attached to wooden stakes and driven into the channel bottom; readings were taken two to three times weekly during early afternoon hours on a Leeds and Northrup 8690-2 millivolt potentiometer. The temperature measurements were found to be within ±0·5 °C accuracy following spot checks with a standard Brooklyn thermometer. Dissolved oxygen and pH were usually analysed weekly in the upper, middle and lower pools at sunrise and 2 p.m.–3 p.m. CST. The dissolved oxygen concentrations were measured in the ambient channel only once in February. Measurements of total hardness, alkalinity and acidity were taken weekly at the lower pools of the two channels. Procedures followed for the chemical analysis were according to Standard Methods (American Public Health Association *et al.*, 1975).

RESULTS

Physical and chemical characteristics

The average weekly water temperature in the heated channel was generally 8 to 10 °C warmer than in the ambient channel (Fig. 3). The maximum water temperature of 40·8 °C was reached in the heated channel on 15 July and 31 °C in the ambient

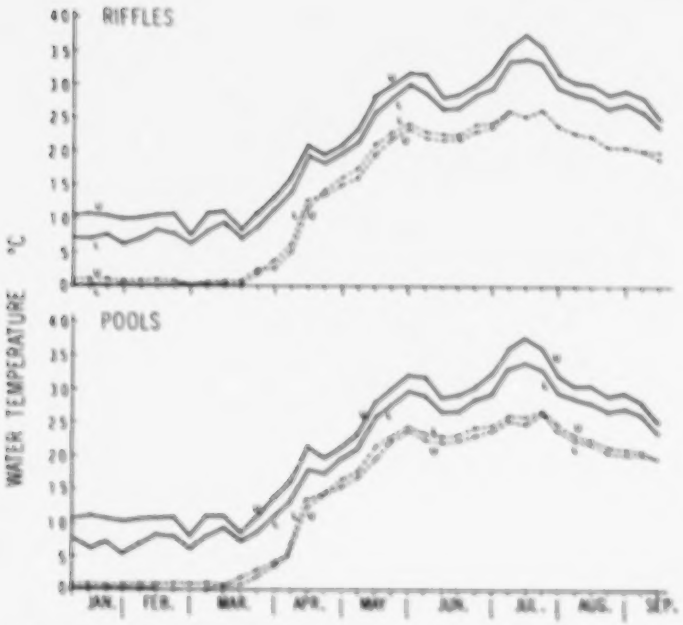

Fig. 3. Weekly mean water temperature of the upper (U) and lower (L) riffles and pools in the ambient (- - -) and heated (——) channels.

channel on 19 July. Throughout the study the lower riffle and pool of the heated channel were 2–5 °C cooler than the upper riffle and pool. During the period of open water (April–September), the lower riffle and pool of the ambient channel remained 1–2 °C warmer than the upper riffle and pool. The maximum substrate temperature reached 39 °C in the heated channel and 28 °C in the ambient channel. The mean water temperature of the heated channel exceeded 20 °C in mid-April and 30 °C from late-May to early-August. In the ambient channel, the water temperature had exceeded 10 °C by mid-April and 20 °C in mid-May to August. Temperatures of the substrate in the heated channel were 2–3 °C cooler in the pools than in riffles. In the ambient channel there was a 1–2 °C difference between the pool and riffle substrates.

Weekly variation in percentage dissolved oxygen saturation was about three times less in the upper than lower channel pools. Similar dissolved oxygen minimum and maximum concentrations were found in both the ambient and heated channels during the period of open water (Fig. 4). Lowest to highest percentage saturation of dissolved oxygen was from 5 % to 220 % in the heated channel in June. Minimum dissolved oxygen concentrations were less than 25 % saturation in the upper pool of

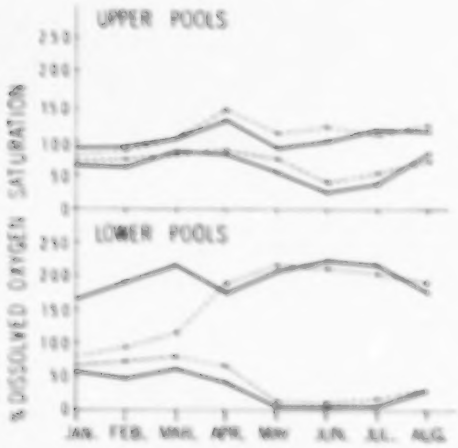

Fig. 4. Monthly maximum and minimum percentage dissolved oxygen saturation in the upper and lower pools in the ambient (·····) and heated (——) channels.

the heated channel in June and in the lower pool in both channels during May through July.

The pH was similar in both channels, ranging from 7·5 to 9·3. Total hardness and alkalinity values varied from 140–170 and 124–148 mg litre $^{-1}$, respectively. Total acidity varied from less than 1–3 mg litre $^{-1}$.

Insect emergence

Dipterans comprised 91 %$_o$ to 92 %$_o$ of the total insects collected from both the ambient and heated channels. Chironomidae comprised 92 %$_o$ of the Diptera with 5 %$_o$ to 6 %$_o$ in the family Ceratopogonidae. The family Chironomidae was separated into subfamilies Chironominae, Orthocladiinae, Tanypodinae and the tribe Tanytarsini, comprising 65 %$_o$, 22 %$_o$, 7 %$_o$ and 7 %$_o$ from the ambient channel and 26 %$_o$, 15 %$_o$, 50 %$_o$ and 9 %$_o$ from the heated channel, respectively. The predominate chironomid taxa from the ambient channel differed from those in the heated channel while the caddisflies, mayflies and damselflies were more similar (Table 1). The chironomids were the only major group emerging from both channels at the beginning of the study.

The largest emergence (81 %$_o$) of Chironominae from the ambient channel was observed from early-May to mid-June. Two emergences occurred in the heated channel; the first from late-April through May (48 %$_o$) and another from mid-August to early-September (44 %$_o$) (Fig. 5(a)). The species *Dicrotendipes fumidus* emerged three to four weeks earlier from the heated channel. Peak emergence of *D. fumidus* in the ambient channel was of longer duration and contained more individuals than in

TABLE 1
PERCENTAGE OCCURRENCE OF MAJOR GROUPS AND IDENTIFIED TAXA WITHIN EACH SUBGROUP

	Ambient channel		*Heated channel*	
	Group	*Taxa*	*Group*	*Taxa*
Diptera				
Chironomidae	84		84	
Chironominae				
Chironomus sp. 1		+		28
Chironomus sp. 2		11		+
Dicrotendipes fumidus Johannsen		76		35
Dicrotendipes modestus Say		+		14
Parachironomus		+		+
Pseudochironomus		+		–
Polypedilum		–		+
Orthocladiinae				
Acricotopus		+		–
Cricotopus		51		71
Paracricotopus		31		+
Psectrocladius		+		–
Tanypodinae				
Ablabesmyia		+		+
Guttipelopia		–		+
Larsia		+		30
Pentaneura		25		+
Procladius		18		+
Tanypus A. nubifer Coquillett		–		38
Tanypus punctipennis Meigen		–		12
Tanytarsini				
Micropsectra		+		14
Tanytarsus sp. 1		56		54
Tanytarsus sp. 2		–		+
Ceratopogonidae	7		6	
Trichoptera				
Agraylea		+		–
Chesmatopsyche		41		+
Hydroptila		48		91
Hydropsyche		+		–
Ephemeroptera	3		2	
Caenis simulans McDunnough		82		94
Callibaetis		18		+
Zygoptera	2		4	
Enallagma		76		75
Ischnura verticalis (Say)		15		16

+, Less than 10 per cent; –, Taxa not found.

the heated channel. In the ambient channel, emergence began at the lower end and shifted toward the upper end of the channel over a period of five weeks. A comparable shift was not observed in the heated channel. Although not a predominate taxon in the ambient channel (Table 1), *Chironomus* sp. 1 emerged 1–2 weeks earlier in the heated channel. Too few specimens of all remaining Chironominae species were collected in either one or both of the channels to make comparisons.

Cricotopus (Orthocladiinae) was collected in the heated channel from late-April to early-May, and from early-May to early-June in the ambient channel indicating advanced emergence of 2–3 weeks (Fig. 5(b)). Few *Paracricotopus* and none of the two remaining Orthocladiinae taxa were recovered from the heated channel (Table 1).

The largest emergence of Tanypodinae occurred from the heated channel in August when 70% of the total was collected. *Tanypus nubifer* was the most abundant species during this period. *Larsia* was collected in the lower end of the heated channel from late-April to early-June and again from late-July through early-September (Fig. 5(c)). Eighty-three percent of the Tanypodinae from the heated channel emerged from the pools; the upper pool produced the greatest number. Significantly greater numbers of Tanypodinae emerged from the heated channel compared with the ambient channel ($p < 0{\cdot}01$, two-way ANOVA).

Tanytarsini emerged in low numbers throughout the study. *Tanytarsus* sp. 1 was collected from the ambient and heated channels from early-May to early-July and from August to early-September. Emergence of *Micropsectra* occurred in April in the heated channel; few were collected from the ambient channel (Fig. 5(d)). An additional species of *Tanytarsus* was found in low numbers only in the heated channel.

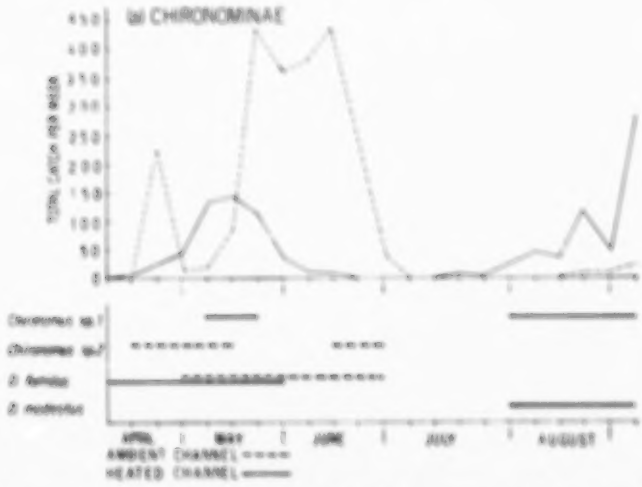

Fig. 5. Emergence of Chironomidae sub-families (a) Chironominae, (b) Orthocladiinae, (c) Tanypodinae, (d) Tanytarsini from the ambient (- - - -) and heated (——) channels. Genus—species listed comprised ≥ 90% of total collected.

(b) ORTHOCLADINAE
(c) TANYPODINAE
(d) TANYTARSINI
APRIL
MAY
JUNE
JULY
AUGUST

Fig. 5 — *contd.*

Similar numbers of Ceratopogonidae were found in both channels; but within a channel there were significant differences found in the total numbers collected at each location. ($p < 0{\cdot}05$, two-way ANOVA). Ninety-eight percent were collected from the middle and lower pools of the heated channel. Only 2 % of the total number of Ceratopogonidae were collected in the upper riffles. A large emergence was observed in both channels in June; the onset was approximately one week earlier in the heated channel. A second emergence occurred from both channels in late-July although the heated channel produced many more individuals than the ambient. The predominate genus was *Probezzia*.

Peak emergence (> 15 individuals) of damselflies (Zygoptera) occurred 4 weeks earlier in the heated channel (Fig. 6(a)). *Enallagma* sp. and *Ischnura verticalis* emerged at approximately the same time from the heated channel; their emergence from the ambient channel was separated by 5 weeks.

Caenis simulans accounted for nearly 90 % of the total Ephemeroptera collected from both channels. The largest emergence was mid-May to mid-June from the ambient channel and early-August to September from the heated channel. Sixty percent of the *Caenis* were from the downstream riffles of both channels. Emergence of *Callibaetis* occurred in small numbers from the ambient channel during May to August and infrequently from the heated channel (Fig. 6(b)).

The genus *Hydroptila* accounted for about 70 % of the total Trichopterans; two-thirds were collected from the heated channel. *Cheumatopsyche* was found primarily in the ambient channel. Emergence of Trichopterans was small and sporadic in both channels until mid-August.

DISCUSSION

Chironomids were the only insect group emerging in both channels at the beginning of the study in early-April when water temperatures varied from 2–5 °C in the ambient and 10–13 °C in the heated channel. Emergence of the mayfly, damselfly, and caddisfly species did not begin until May when temperatures were 5–10 °C higher in both channels. The onset of insect emergence has been attributed to rising water and mud temperatures (Hilsenhoff, 1966; Macan & Maudsley, 1966; Brittain, 1976) and photoperiod changes (Danks, 1978). Therefore, both temperature and photoperiod may have been involved during the onset of emergence and appear not to be separable.

The elevated water temperature in the heated channel advanced the adult emergence of several species. Peak emergence periods were advanced by one to four weeks for two Chironominae, one Orthocladiinae, one Ceratopogonidae and one damselfly species. Coutant (1967) found that a 1 °C rise in ambient temperature in the Columbia River advanced emergence of a hydropsychid caddisfly and Wrenn *et al.* (1979) observed *Caenis* sp. mayflies and chironomids emerging 10 days to 4 weeks

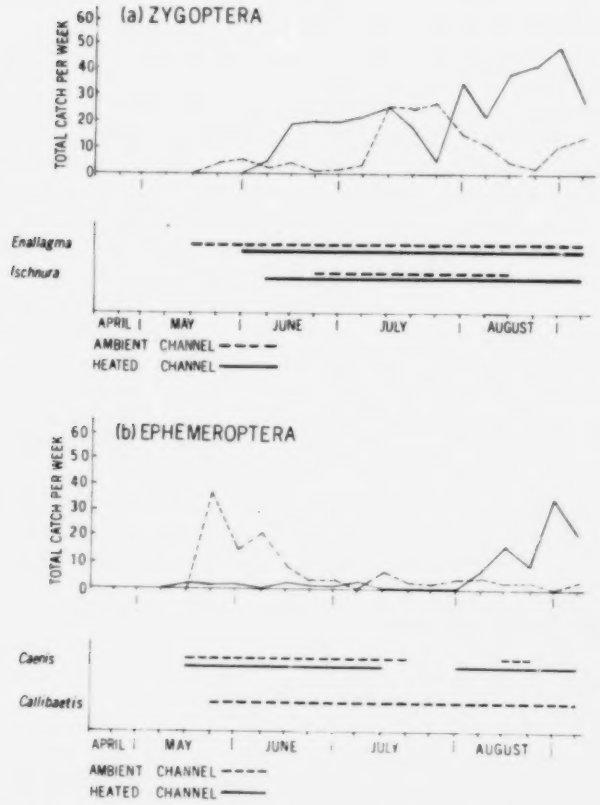

Fig. 6. Emergence of (a) Zygoptera and (b) Ephemeroptera collected from the ambient (----) and heated (——) channels. Genera listed comprise ≥90% of the total collected.

earlier in outdoor channels heated 4–6 °C above ambient. However, Langford & Daffern (1975) could not conclude that advanced emergence occurred in the Severn River in England where water temperatures were elevated up to 7 °C above ambient.

Large diel changes in dissolved oxygen were found in both the ambient and heated channels. Surber & Bessey (1974) presented data showing that many aquatic insects have a high short-term tolerance (less than 12 h) to dissolved oxygen concentrations less than 2 mg litre^{-1}. Curry (1965) in his review found several chironomids able to withstand dissolved oxygen concentrations of 1 mg litre^{-1}. Insects continued to emerge from the lower channel pools despite dissolved oxygen concentrations of 1 mg litre^{-1} during the months of May and June.

Emergence of insects throughout the study suggests a greater thermal tolerance than expected. Temperatures of about 32 °C have been suggested by Coutant (1962) as the upper tolerance level for achieving normal population structures although some chironomids tolerated water temperatures up to 43 °C. Temperatures exceeding 40 °C (Miller *et al.*, 1976) and 42 °C (Durrett & Pearson, 1975) were found to eliminate invertebrates from aquatic ecosystems. In our study, few insects emerged from the heated channel during the period of maximum temperature (40–41 °C). The damselflies were the most prevalent group of those that did emerge. As the temperatures decreased to 35 °C more insect groups emerged. The high temperatures near 40 °C may have inhibited adult emergence as shown for other insects at lower temperatures (Nebeker, 1973; Brittain, 1976).

Results gathered in this study did not show a change in insect voltinism. Newell & Minshall (1978) observed that a mayfly species was multivoltine near a spring source held approximately constant at 18 °C while the same species was bivoltine in the same downstream water where temperatures had a normal seasonal fluctuation. Wrenn *et al.* (1979) in their outdoor channel study found an increased potential for additional generations of *Caenis* mayflies in channels with water temperatures elevated 4–6 °C above ambient.

This study demonstrated that insect emergence patterns were altered during the spring and summer months in an outdoor channel elevated 10 °C above ambient temperature. To determine if the synchrony and ultimate population success of the insects would eventually be threatened by elevated water temperature, the emergence patterns would have to be studied over a longer period of time.

ACKNOWLEDGEMENTS

The authors owe their gratitude to Mr Glen R. Endicott for designing and constructing the emergence traps. Mr John T. Shyne helped devise and assist in the sampling programme, Dr Edwin F. Cook, University of Minnesota, confirmed the insect identifications and Dr Gerald Ericksen, St. Olaf College, Northfield, Minnesota, performed the statistical analysis. We thank Drs R. J. Hall and K. E. F. Hokanson for critically reviewing the manuscript.

REFERENCES

American Public Health Association, American Water Works Association, Water Pollution Control Federation (1976). *Standard methods for the examination of water and wastewater*, 14th ed. Washington, DC.

Brittain, J. E. (1976). The temperature of two Welsh lakes and its effects on the distribution of two freshwater insects. *Hydrobiologia*, **48**, 37–49.

Coutant, C. C. (1962). The effect of a heated water effluent upon the macroinvertebrate riffle fauna of the Delaware River, *Proc. Pa. Acad. Sci.*, **36**, 58–71.

COUTANT, C. C. (1967). Effect of temperature on the development rate of bottom organisms. In: *Biological effects of chemical discharges*, 11–12. Ann. Rep., Pacific NW Lab., US Atomic Energy Comm., Div. Biol. Medicine.

CURRY, L. L. (1965). A survey of environmental requirements for the midge (Diptera: Tendipedidae). In: *Biological problems in water pollution*, ed. by C. M. Tarzwell, 127–41. Cincinnati, Ohio, US Dept. Health Educ. and Welfare, Public Health Serv.

DANKS, H. V. (1978). Some effects of photoperiod, temperature, and food on emergence in three species of Chironomidae (Diptera). *Can. Ent.*, **110**, 289–300.

DURRETT, C. W. & PEARSON, W. D. (1975). Drift of macroinvertebrates in a channel carrying heated water from a power plant, *Hydrobiologia*, **46**, 33–43.

HILSENHOFF, W. L. (1966). The biology of *Chironomus plumosus* (Diptera: Chironomidae) in Lake Winnebago, Wisconsin, *Ann. ent. Soc. Am.*, **59**, 465–73.

LANGFORD, T. E. & DAFFERN, J. R. (1975). The emergence of insects from a British river warmed by power station cooling-water, *Hydrobiologia*, **46**, 71–114.

MACAN, T. T. & MAUDSLEY, R. (1966). The temperature of a moorland fish pond, *Hydrobiologia*, **27**, 1–22.

MILLER, M. C., HATER, G. R., FEDERLE, T. W. & REED, J. P. (1976). Effects of power-plant operation on the biota of a thermal discharge channel. In: *Thermal ecology*, II. ed. by G. W. Esch & R. W. McFarlane, 251–8. Augusta, GA, Technical Information Center, Energy Research and Development Adm., CONF-754025.

MOUNT, D. I. (1969). Developing thermal requirements for freshwater fishes. In: *Biological aspects of thermal pollution*, ed. by P. A. Krenkel & F. L. Parker, 140–7. Nashville, Tennessee, Vanderbilt University Press.

NEBEKER, A. V. (1971). Effect of high winter water temperature on adult emergence of aquatic insects, *Wat. Res.*, **5**, 777–83.

NEBEKER, A. V. (1972). Effect of low oxygen concentration on survival and emergence of aquatic insects, *Trans Am. Fish. Soc.*, **101**, 675–9.

NEBEKER, A. V. (1973). Temperature requirements and life cycle of the midge *Tanytarsus dissimils* (Diptera: Chironomidae), *J. Kans. ent. Soc.*, **46**, 160–5.

NEWELL, R. L. & MINSHALL, G. W. (1978). Life history of a multivoltine mayfly, *Tricorythodes minutus*: an example of the effect of temperature on the life cycle, *Ann. ent. Soc. Am.*, **71**, 876–81.

SURBER, E. W. & BESSEY, W. E. (1974). Minimum oxygen levels survived by stream invertebrates. *Bull. Va. Polytech. & State Univ.*, No. 81.

WRENN, W. B., ARMITAGE, B. J., RODGERS, E. B. & FORSYTHE, T. D. (1979). *Browns Ferry Biothermal Research Series II. Effects of temperature on bluegill and walleye, and periphyton, macroinvertebrate, and zooplankton communities in experimental ecosystems*. Duluth, MN, EPA Ecological Research EPA-600/3-79-092.

A SELECTION OF BOOKS PUBLISHED BY APPLIED SCIENCE PUBLISHERS

BIOLOGICAL MONITORING OF INLAND FISHERIES
edited by J. S. Alabaster
6 × 9". xvi + 226 pages. 22 illus.

ECOLOGICAL ASPECTS OF THE TOXICITY TESTING OF OILS AND DISPERSANTS
edited by L. R. Beyson and E. B. Cowell
6¼ × 10". viii + 149 pages. 26 illus.

ECOLOGICAL EFFECTS OF OIL POLLUTION ON LITTORAL COMMUNITIES
edited by E. B. Cowell
6 × 9". vii + 248 pages. 86 illus.

ENVIRONMENTAL IMPACT OF MINING
by C. G. Down and J. Stocks
6 × 9". ix + 371 pages. 108 illus.

ESTUARINE ENVIRONMENT
edited by R. S. K. Barnes and J. Green
6 × 9". xii + 133 pages. 33 illus.

LEAD IN THE ENVIRONMENT
edited by P. Hepple
6 × 9". ix + 82 pages. 7 illus.

MARINE ECOLOGY AND OIL POLLUTION
edited by Jenifer M. Baker
6 × 10". vii + 566 pages. 168 illus.

A SELECTION OF BOOKS PUBLISHED BY APPLIED SCIENCE PUBLISHERS

MOSQUITO ECOLOGY: FIELD SAMPLING METHODS
by M. W. Service
6 × 9". xii + 583 pages. 75 illus.

PETROLEUM AND THE CONTINENTAL SHELF OF NORTH WEST EUROPE: VOLUME 2: ENVIRONMENTAL PROTECTION
edited by H. A. Cole
8¼ × 11¼". vii + 126 pages. 37 illus.

WASTE TREATMENT IN AGRICULTURE
by P. N. Hobson and A. M. Robertson
6 × 9". x + 254 pages. 21 illus.

BIODETERIORATION INVESTIGATION TECHNIQUES
edited by A. Harry Walters
6 × 9". xii + 346 pages. 81 illus.

PROCEEDINGS OF THE 3RD INTERNATIONAL BIODEGRADATION SYMPOSIUM
edited by J. Miles Sharpley and Arthur M. Kaplan
6¼ × 10". xiv + 1138 pages. 452 illus.

ANIMAL WASTES
edited by E. Paul Taiganides
6 × 9". xvi + 429 pages. 98 illus.